Deep Space Systems Technology Program (X2000) – Future Deliveries and Biomorphic Explorers

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Manager, DSST Future Deliveries

The DSST (Deep Space Systems Technology) Program is a series of projects tasked with system-level development and delivery of the core technologies needed for future deep space science missions. It is intended to move high technology from the lab bench to flight through project implemented system deliveries of leap-ahead hardware and software. The program consists of four major parts:
- projects tasked with system level deliveries (X2000 or 1st Delivery, and Future Deliveries),
- an advanced avionics and computing element being implemented by CISM (the Center for Integrated Space Microsystems), and
- an Advanced Radioisotope Power Source (ARPS) element.
- an integrated Mission Data System (flight and ground software for space science systems).

The first project (1st Delivery) in the program is called X2000. It focuses on providing to the next wave of deep space missions the advanced avionics, flight and ground software (Mission Data System), and other key components they will need. While the technology is impressive, the scope and focus is such that it offers little in technologies common to biomorphic explorers.

Future deliveries, particularly Delivery 2 and Delivery 3, are being scoped at this time. While plans are not yet detailed, some very small sensor systems may be a part of deliveries in the 2003 and later time frame. At the very least, many of the low power, low mass and volume avionics and other technologies may have common development paths with those needed for biomorphic explorers.

The advanced avionics and computing work in DSST (CISM) will certainly contribute to the development of biomorphic explorers. The System on a Chip (SOAC) activity strives to miniaturize and integrate chips of all types (digital, analog, power, RF, MEMs) to arrive at full systems on a single chip. The Revolutionary Computing Technologies element in CISM involves efforts to dramatically improve computing capabilities for space systems. It includes "bio-mimetic systems", which studies biological living things (like fish, mice, etc.) to learn from nature's solutions how to more effectively interact with the environment. In addition, the RCT program is conducting research in "gene regulation." This task strives to model the living organism (like the C. Elegans worm), as a computer system, and thus understand the 'bio-machinery' behind cell replication, mutation, functional development, regeneration, survivability, etc. Quantum computing, and evolvable hardware are other examples of technologies that could contribute to the development of biomorphic explorers.

The ARPS element of the program focuses in the near term on the needs of the next wave of outer planets missions. It will produce an AMTEC based (Alkali Metal Thermal to Electric Converter) radioisotope power source of the 150 Watt class. Development of other advanced power sources is planned in the timeframe of Delivery 2 and later (mid next decade). The likely direction for the main focus of this element for future deliveries is smaller power sources in the ~10's of Watts. In addition, some attention may be given to very small (<<1kg, <1W) power sources that may be of use to biomorphic explorers.

There are potentially a number of areas between the Deep Space Systems Technology Program and Biomorphic Explorers that will require similar technology. Miniature avionics, space computing technologies, and radioisotope power sources are all promising areas of DSST focus that may be applicable to these very small systems. The biomorphic community should closely monitor the work in DSST to take full advantage of the technology that it will be developing for other deep space needs.

Deep Space Systems Technology Program (X2000)

Program Overview for the
1st NASA/JPL Workshop on Biomorphic Explorers for Future Missions

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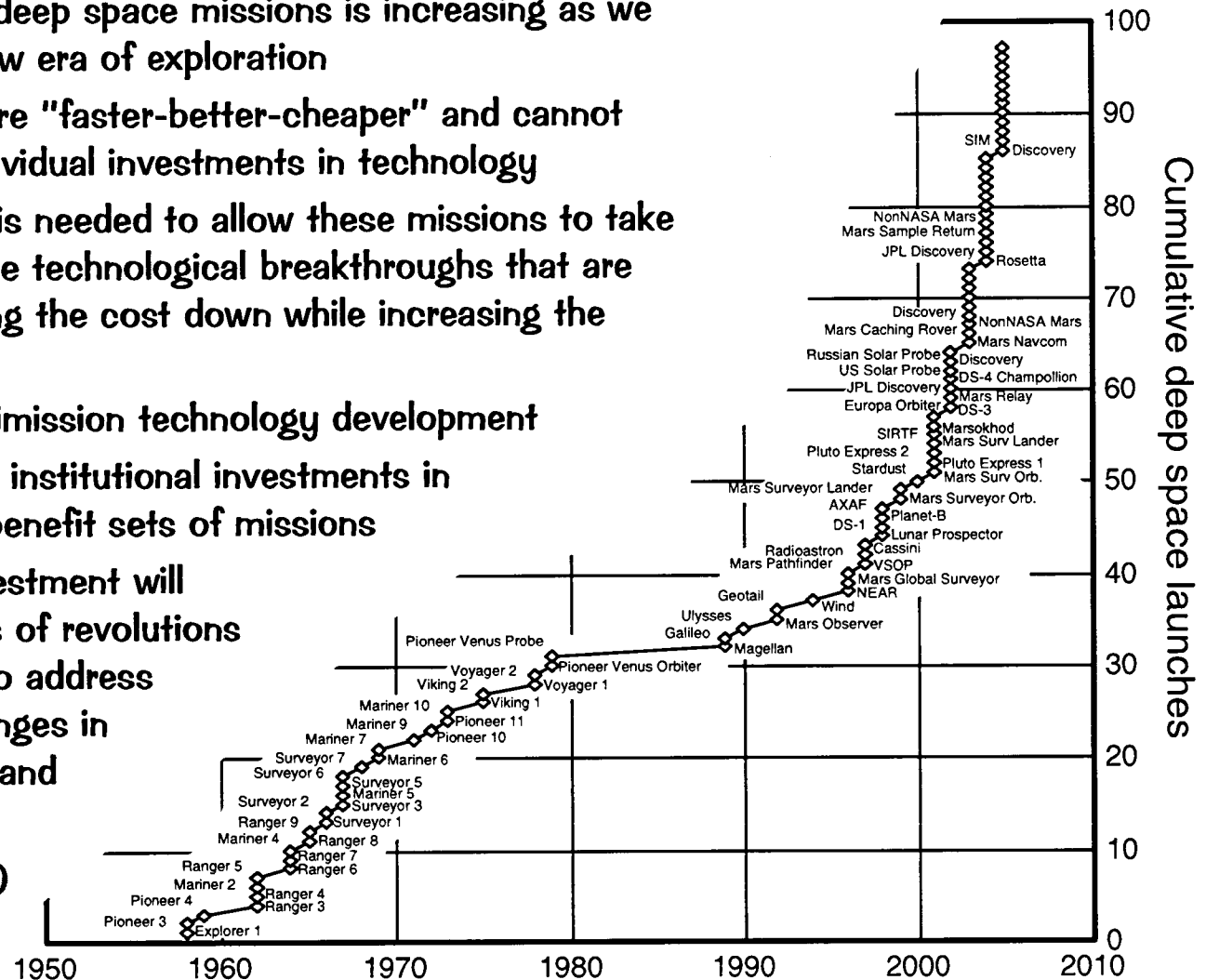Les Deutsch - Program Manager
Benny Toomarian - Revolutionary Computing

Leon Alkalai - CISM Manager
Elizabeth Kolawa - Systems on a Chip

DSST Program Context

2000
Deep Space
Systems Technology
Future Deliveries

JPL

- The number of deep space missions is increasing as we embark on a new era of exploration

- New missions are "faster-better-cheaper" and cannot afford large individual investments in technology

- A new process is needed to allow these missions to take advantage of the technological breakthroughs that are critical to getting the cost down while increasing the science

- The key is multimission technology development

- NASA will make institutional investments in technology to benefit sets of missions

- Continuous investment will provide a series of revolutions in technology to address common challenges in mission design and execution
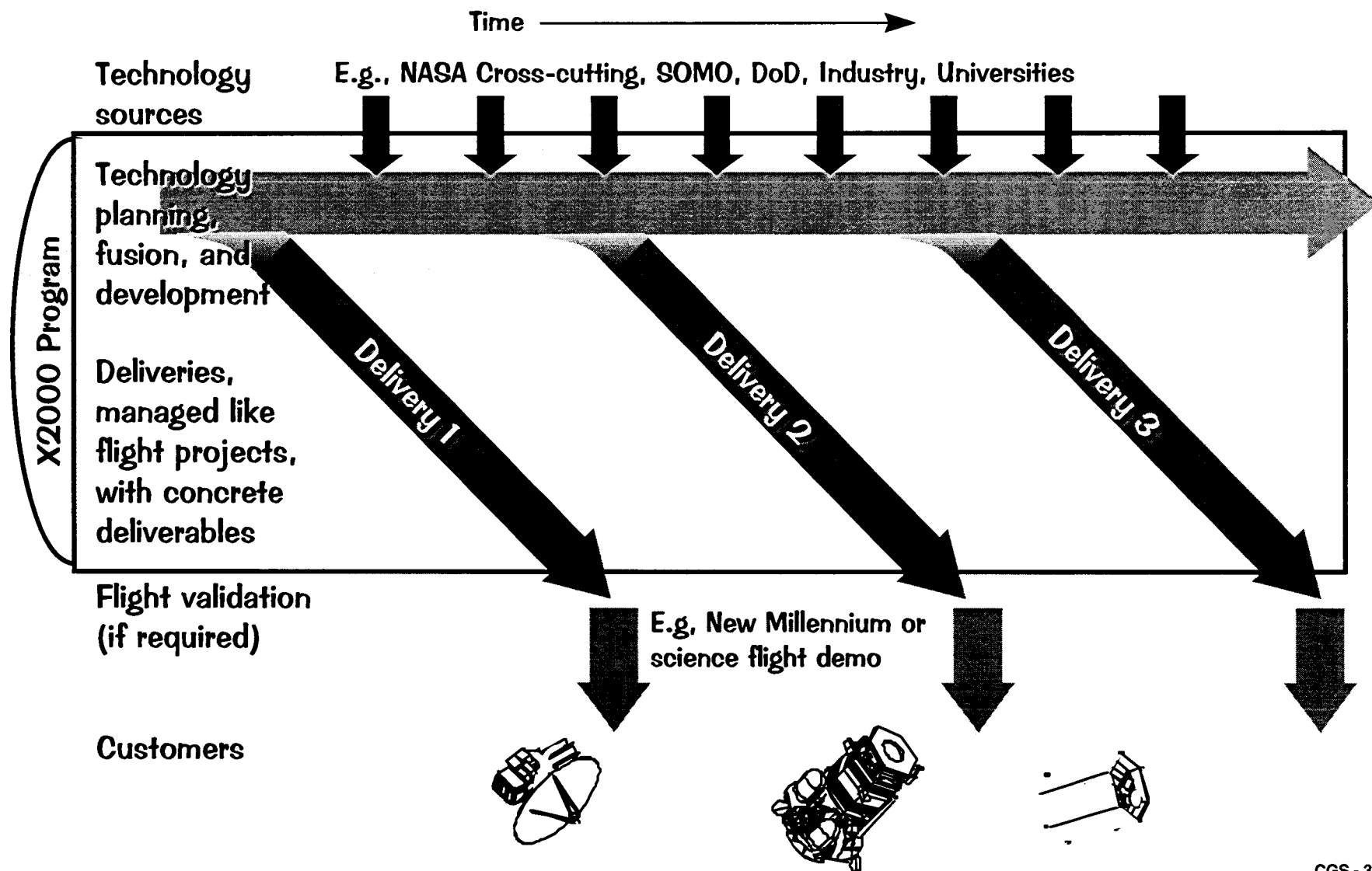
- This is X2000

Cumulative deep space launches

X2000 Concept

NASA
JPL

2000
Deep Space
Systems Technology
Future Deliveries

Time ⟶

Technology sources

E.g., NASA Cross-cutting, SOMO, DoD, Industry, Universities

X2000 Program

Technology planning, fusion, and development

Deliveries, managed like flight projects, with concrete deliverables

Delivery 1

Delivery 2

Delivery 3

Flight validation (if required)

E.g, New Millennium or science flight demo

Customers

CGS - 3
08/20/98

JPL

- **Deep Space System Technology (X2000), is comprised of 3 NASA budget Lines:**

	FY98	FY99	FY00	FY01 ($M)
Advanced Flight Systems (Deliveries & Mission Data System)	23	24	48	48
Center for Integrated Space Microsystems (CISM)	9	12	16	14
Advanced Radioisotope Power Source (ARPS)	10	10	10	10
Total	42	46	74	71

Cassini

1000 kg

Mars
Pathfinder   Lewis   Clark

NEAR   Solar Probe

Mars 98 Lander/Orbiter   Pluto/Kuiper
Express

100 kg

Stardust   Europa
Orbiter

Spacecraft Mass

10 kg

"Microspacecraft"

Past   Present   Future
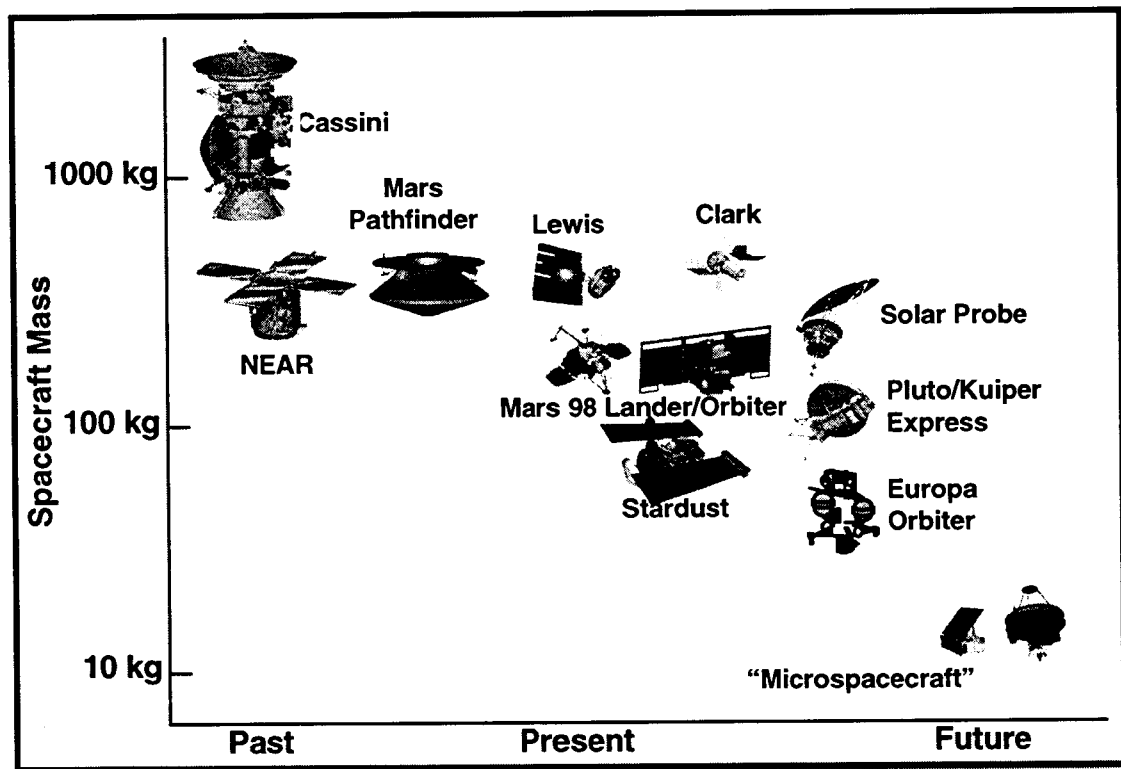
X2000's Bottom Line:

Dramatic technology
breakthroughs

Enable low-cost missions

Science-driven architecture

Progressive spacecraft
miniaturization

- **X2000 fosters an evolution of flight avionics to enable smaller, less expensive, and more capable spacecraft**
  - **This is a cornerstone of the X2000 program**

SSPA

Small Deep
Space Transp'dr

Conventional
Valve Driver
Electronics

Conventional power
conversion, control,
and pyro electronics

Opt-Comm

ADV
SSPA

X and Ka Band
Downlink

Tiny
Transp'dr X Uplink

Galileo
Functions
on a card

Cassini
Functions
on a chip,
assemblies
on a card

Power
Activated
Switching
Module

Conventional
HCD/RSDL elect.

I/O MCM
mass DRAM
local DRAM
Flight
Computer
MCM

Data
Buses

Neural Net
Digital Sig Proc
Valve Drive
Pyro SW
Ext Pwr Cntrl
Int Pwr Cntrl
Programmable I/O
Mass Memory
Flight Computer
with local
memory

Power
Bus

Integrated Instr.
Optical/Comm
Radio
S.G. Ext Pwr
Switching
S.G.Pwr.MCM
S.G. Proc:
Neural, DSP
Second
Generation
CPU/memory/
I/O MCM

DSI
Some assemblies on a chip

X2000 First Delivery
Assemblies on a chip

Future Delivery
Subsystems
on a chip

Far Term
"Spacecraft
on a chip"

Focus Technology on Future Science Mission Needs
(some illustrative examples)

2000
Deep Space
Systems Technology
Future Deliveries

NASA **JPL**

Need advanced capabilities in many diverse systems: Orbiters, landers, probes, rovers, aircraft, networks, sub-surface, submarine, penetrators, aerobots, ...?

Mars/Venus Aerobot

Benefit to Solar System Exploration and more: Discovery, Mars, Earth Science, Space Physics, DoD, ...

Space Physics Networks

Small Body In-Situ Exploration and Sample Return

Saturn Ring Observer

Very Large Aperture Systems

Outer Planet Deep Multi-Probes

Titan Organic Explorer

Europa Lander

CGS - 6
08/20/98

- On 4-6 year centers, revolutionize the *flagship mission, full spacecraft* capability.
- In between these deliveries, enable *new systems* for new exploration approaches and provide a path for progress towards the next revolution.

a *sharpening* of traditional capabilities (orbiters, flybys, probe carriers, landers, etc.),

a *broadening* of the exploration toolset (daughter s/c, aerobots, sub-surface systems, etc.)
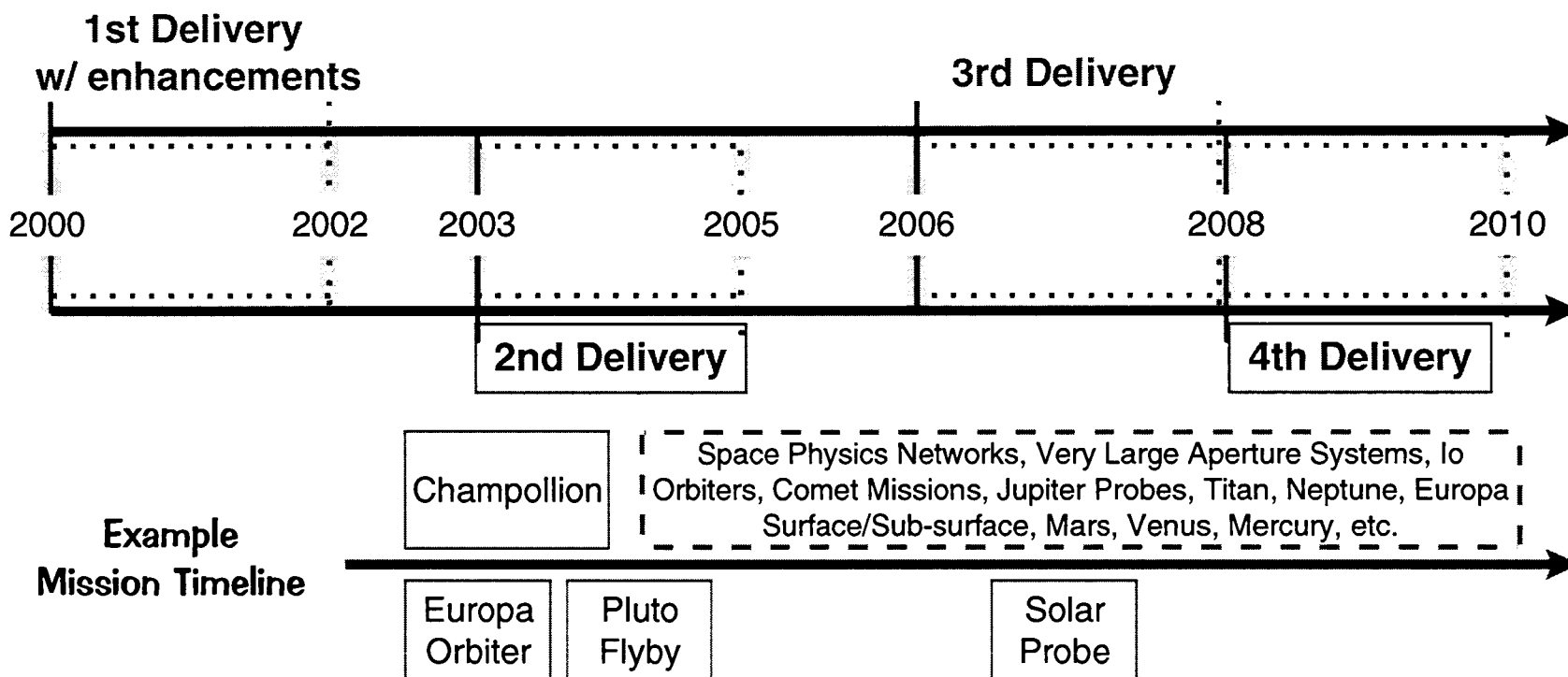
1st Delivery
w/ enhancements

3rd Delivery

| 2000 | 2002 | 2003 | 2005 | 2006 | 2008 | 2010 |

2nd Delivery

4th Delivery

Example Mission Timeline

| Champollion | Space Physics Networks, Very Large Aperture Systems, Io Orbiters, Comet Missions, Jupiter Probes, Titan, Neptune, Europa Surface/Sub-surface, Mars, Venus, Mercury, etc. |

| Europa Orbiter | Pluto Flyby | | Solar Probe |

CGS - 7
08/20/98
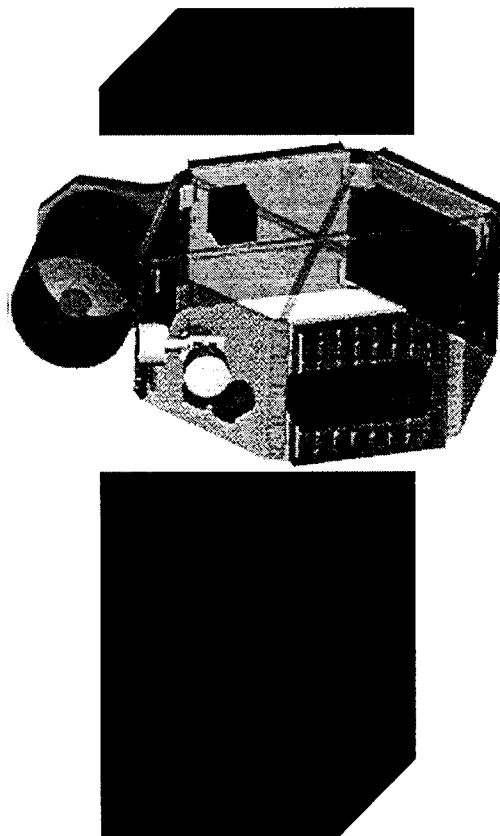
X2000 S/C Electronics

- Power Electronics
- Telecom processing
- 3D MCM standard
- Integrated Architecture
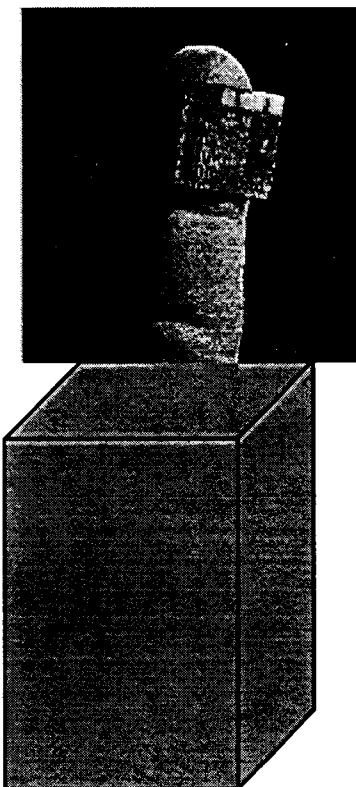
Avionics System on a Chip

- Start design and fabrication of minimum avionics system on a chip.
- Include Telecom, Power Management, CPU, Memory, and Sensors.
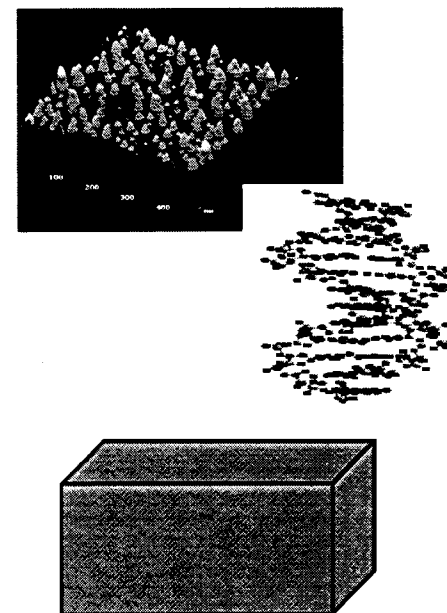
Revolutionary Computing

- Reconfigurable Computing
- DNA Computing
- Quantum Computing
- MEMS-Optics, etc.
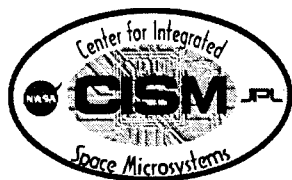
CGS - 8
08/20/98

Revolutionary
Computing Technologies
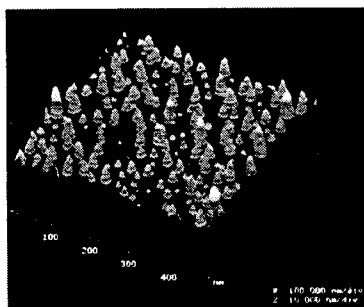
Quantum Dots
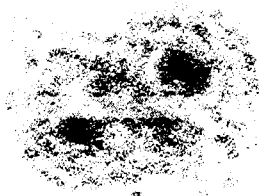
Quantum Computing

Optical Computing

Atomic scale physics

STM Micrograph | Atomic Layers | Practical devices

Macroscopic currents and radiation

Systems on a chip
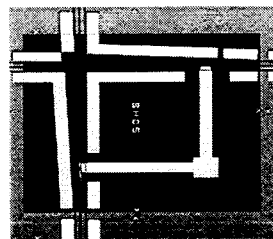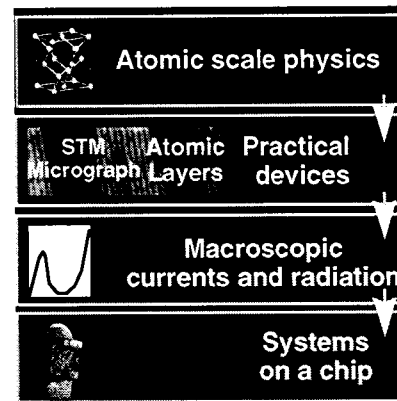
Nano-technology Modeling

Mission "inspiring"

Breakthrough Revolutionary Computing Technologies & Architectures

Biological Computing
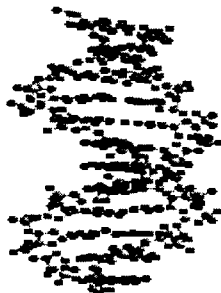
DNA Computing
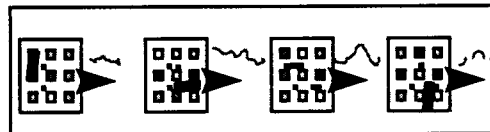
Evolvable Hardware

Reconfigurable Computing

Objectives:

- Develop a spaceflight-quality reconfigurable computing capability which will allow:
    - Faster, cheaper development cycles
    - In-flight failures to be fixed via reconfiguration, resulting in higher reliability
    - Hardware-based algorithms to be reconfigured in flight in response to changing conditions
    - A common hardware assembly to perform multiple functions

Approach:

- Developing HW & SW environment that will enable use of reconfigurable FPGA
- Demonstrate static reconfigurability on selected X2000 applications
- Demonstrate dynamic reconfigurability on rover navigation based on stereo vision

Imaging Data   Navigation Data

I/O

Support Function FPGA

MEM controller & communication ports

function controls

Expandable to multiple FPGA's or replaced with single chip multi-program layer FPGA

PRGM, test & monitor interface

DATA Bus

ADDR Bus

8 bit µc

FPGA Program Memory

Low speed host serial link
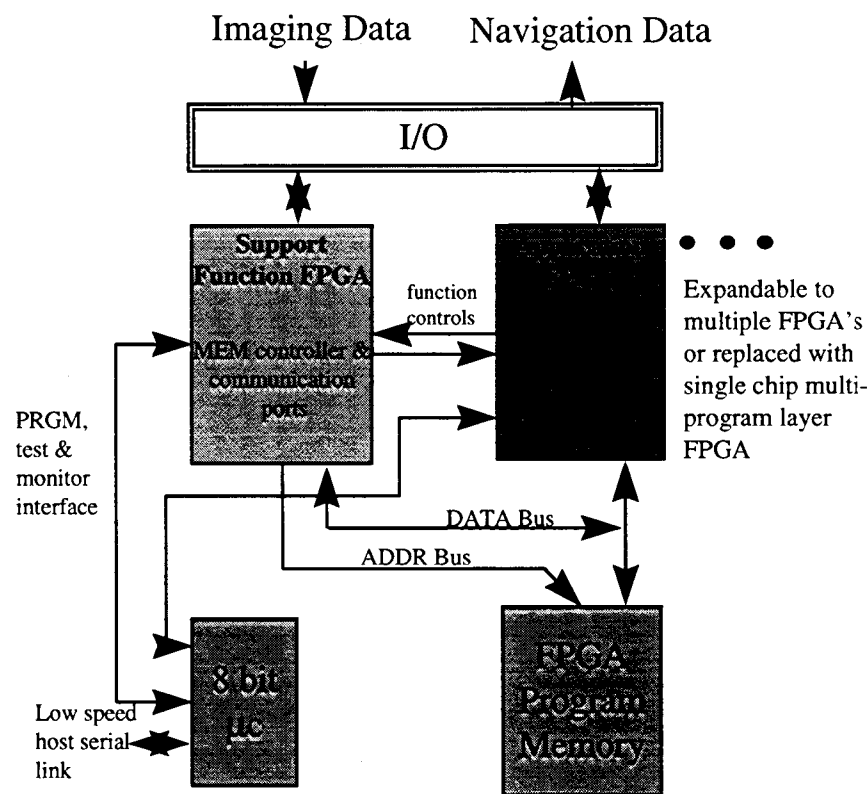
Applications for Future Space Missions:

- X2000, In-situ science, multi-spectral imaging, and many other space science applications.
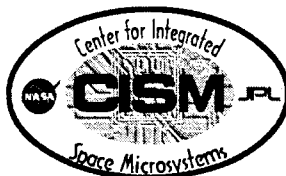
Objective: Develop microelectronics chips capable of self-reconfiguration for adaptation to the environment

Genetic Algorithm   Electronics
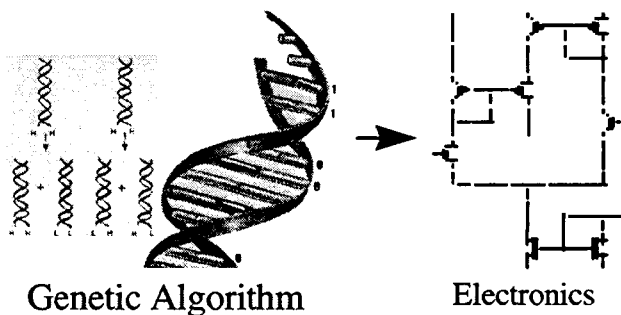
Payoff: Achieve high autonomy on-board spacecraft

• Maintain functionality under changes in operating conditions

•

• Provide new functions, not anticipated on ground

Approach:

• Use reconfigurable cells

•

• Achieve self-organization by reassigning cell function & conncetions between cells

•

• Use powerful parallel searches (e.g. genetic algorithms) directly in hardware, to evolve chip architecture

-

Biomimetic Computing

Goal

Use information processing
techniques derived from biology
to enhance and/or add
sensing capabilities

Electrosensory System

Features

Very high sensor sensitivities
even with poor individual detectors
and in the presence
of significant noise

Benefits

Expanding spacecraft science
and engineering/navigation
sensing options and increasing
sensitivities and resource use
efficiency

Potential

Highly efficient sensing systems
approaching theoretical limits
of sensitivity

Challenges

Understanding biological processing techniques and
applying the techniques to important applications

Systems on a Chip
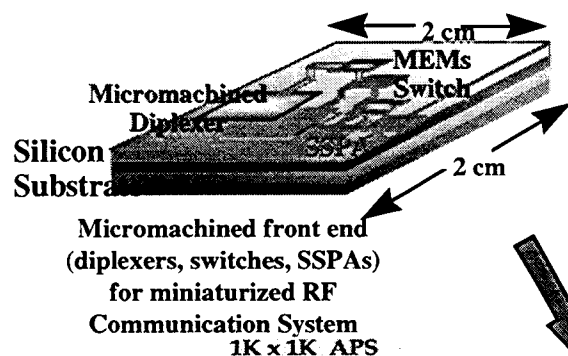
X2000 First Delivery: ~10,000cc, ~60 kg, ~150W

Micromachined Diplexer

MEMs Switch

Silicon Substrate

2 cm

2 cm

Micromachined front end
(diplexers, switches, SSPAs)
for miniaturized RF
Communication System

1K x 1K APS

Power & bias

Clock in

Digital out

Active Pixel Sensors for low
power optical comm. and
advanced Star Trackers

SOAC: <100cc, <1 kg, ~ 30 -50W
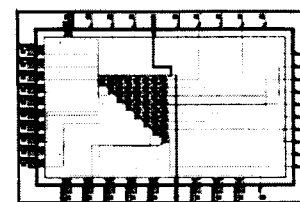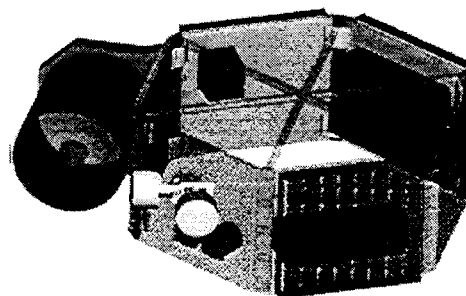
Ultra Low Power
architecture and devices
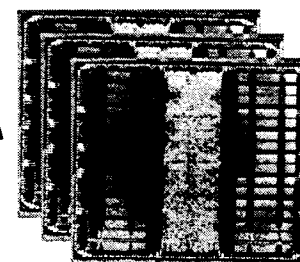
Processor in memory:
Multiple CPU per chip
with DRAM, SRAM,
NVRAM, BIST, Fault
Tolerance

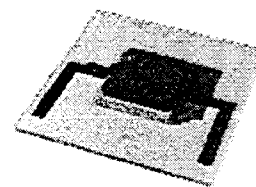Si_3N_4 Insulator

Vias

Magnetic Material

Conductor

Thin film microtransformers
and passive components for
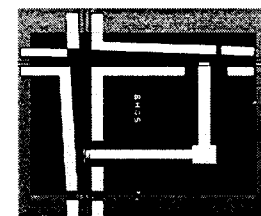miniaturized Power
Management and Distribution
System
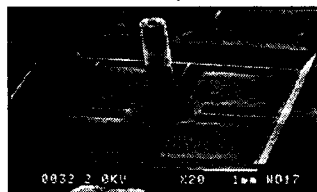
Micromechanical Inertial
Reference System for
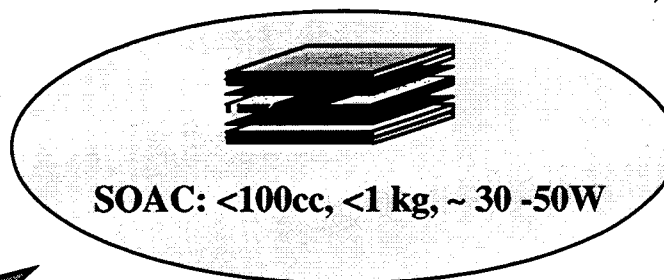miniaturized Guidance
and Navigation System
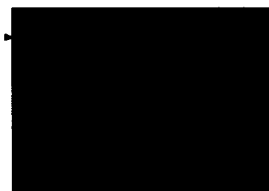
Thermoelectric thin film
coolers for advanced
thermal control

Thin film batteries for
on
chip power storage

High bandwith, low
power, optoelectronic
switch for high speed
optical bus

- Definition:
    - Highly capable, autonomous avionics system which includes CPU, mass memory, power management and distribution, telecomm, and sensors; all integrated into a single monolithic unit.
- Benefits:
    - Volume/Mass reduction
    - Improved performance and reliability
    - Power reduction
- Applications:
    - Spacecraft
        - Micro Spacecraft
        - Science Craft
        - Micro Probe
    - Aerobots
    - Micro and Nano Rovers
    - Biomorphic Explorers
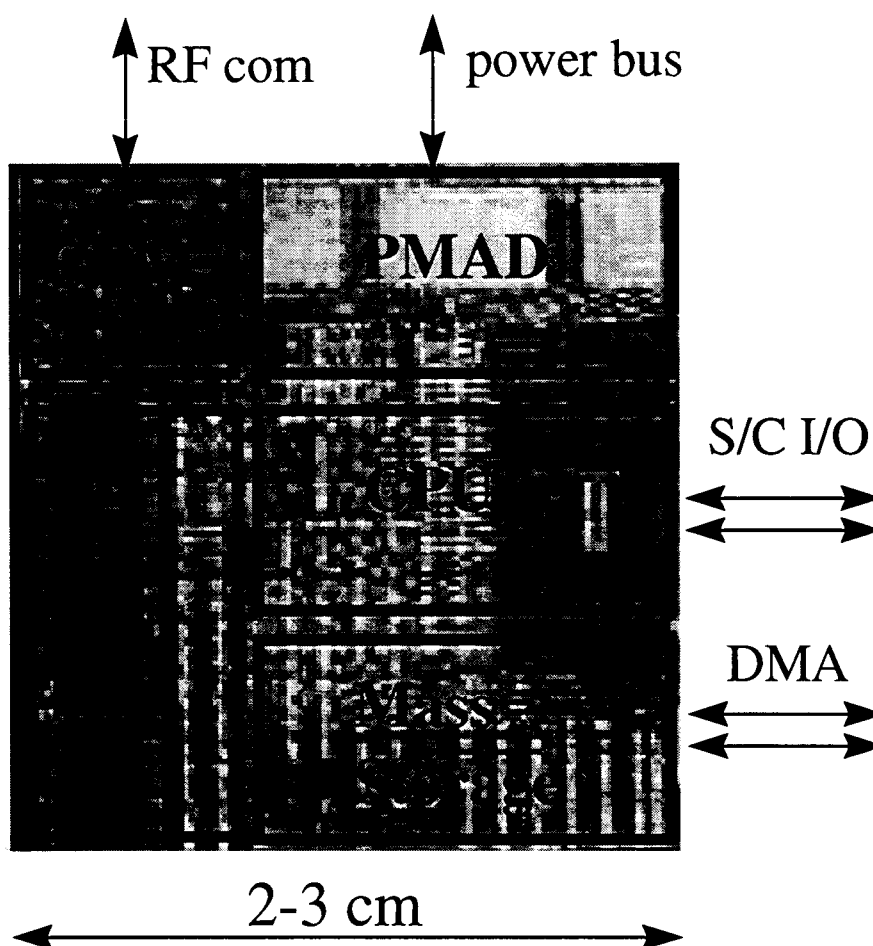
RF com   power bus

PMAD

S/C I/O

DMA

2-3 cm

The Pathfinder system on a chip was selected for multiproject Darpa run at MIT Lincoln Lab as a collaborative effort between U. Illinois-Chicago and SOAC/CISM.

Chip architecture:
- 50 MHz, 8-bit RISC CPU
- 256-kByte SRAM
- RF I/O control
- UHF tranceiver
- on-chip power management and regulation
- on-chip clock generation

Technology:
- already fabricated using MOSIS AMI process: 1.2 um bulk n-well CMOS
- will be fabricated using 0.25 um SOI CMOS in FY'98, 0.18 um in FY'99 in collaboration with LL, Darpa, and industry.
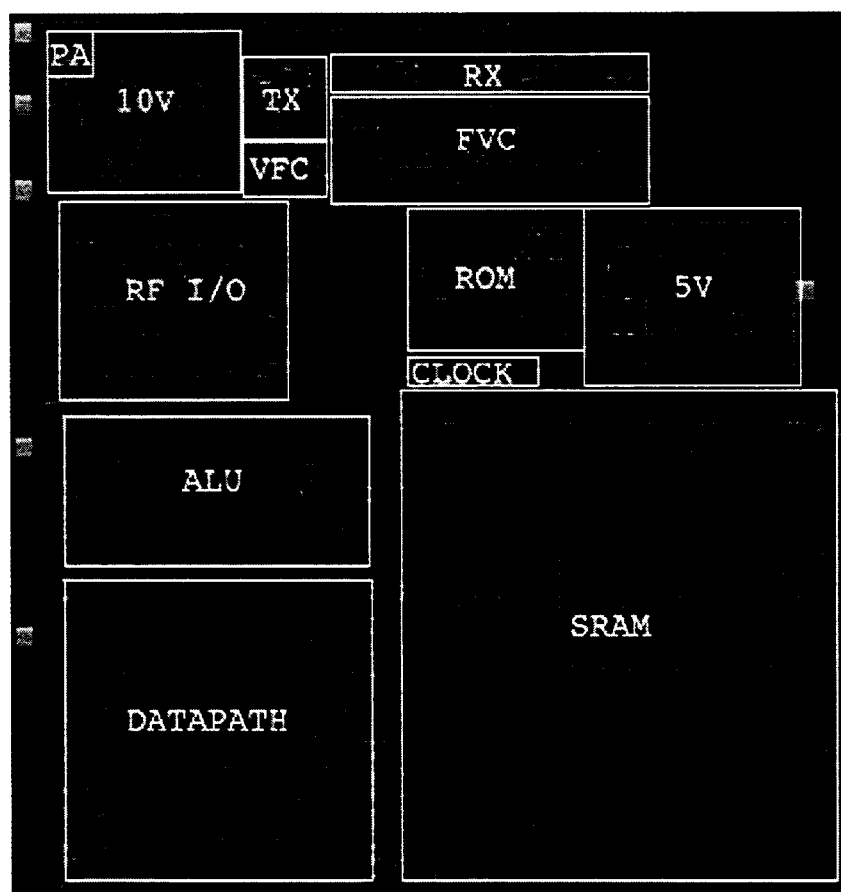
University of Illinois-Chicago UIC chip